A Multi-Wavelength Mini Lidar for Measurements of Marine Boundary Layer Aerosol and Water Vapor Fields

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LONG-TERM GOAL

Our long-term goal is to improve our understanding of dynamics of marine aerosols and water vapor fields in the coastal marine boundary layer. To achieve this goal, we have measured 4-D distribution of aerosol fields in the lower-marine boundary layer (L-MBL) with a multi-wavelength scanning lidar system. Once the system is well calibrated and sufficient representative data are collected, we will use these data to develop models of the aerosol fields.

SCIENTIFIC OBJECTIVES

Our scientific objectives are to improve models of the aerosol optical properties in the coastal marine boundary layer (MBL). Although various aerosol models exist, most of these are for the open ocean and few if any models can describe the boundary layer's aerosol optical properties where breaking waves and complex atmospheric dynamics exist. We plan to develop models of the vertical aerosol structure in the 15 m of the atmosphere directly above the ocean surface. In order to develop models of this type, measurements are needed which can map out the aerosol optical properties over space and time as a function of wave heights and meteorological conditions.

APPROACH

Our approach is to use a scanning multi-wavelength lidar to measure the 4-D (space and time) aerosol optical fields in order to characterize the aerosol properties at various marine setting.. These measurements were carried out at two coastal locations on Oahu - Makai Research Pier and currently at Bellows Air Force (AFS) close to the University of Hawaii's Meteorological Tower (21^{o} 21.848' N, 157^{o} 42.584' W). Measurements were made under various wave and wind conditions in order to obtain broad and representative data sets. We are collecting these data in order to test existing Navy aerosol models for the coastal environment. We have found that lidar calibration is a very important issue and we are making a concerted effort in this area by employing a number of independent but related tests. Such tests should characterize the lidar's calibration and the aerosol phase function at 180 degrees, both of which are required to correctly derive the aerosol scattering coefficient.

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WORK COMPLETED

For measuring four-dimensional aerosol optical properties, we have used a 12" multi-wavelength scanning lidar, developed with joint DURIP,ONR and UH funding. This lidar is based on a 20 Hz Nd:YAG solid state laser capable of radiating collinear laser beams of 8 nanosecond pulses at 1064 nm (< 1.6 J), 532 nm, 355 nm and 266 nm. Any variations in the peak to peak laser pulses are measured with APDs at 532 and 1064 nm and used to normalize the lidar backscatter data. We also employ a fixed target which allow us to make a day to day relative calibration of the optical efficiency of the scanner mirrors which quickly become coated with sea salt.

We have made precise 4-D measurements of backscatter at 532 and 1064 nm. During the period Jan - May 1998, the lidar system was used at Makapu'u (Makai Research Pier site), on the East side of the island of O'ahu. The lidar system was relocated near the beach at Bellows AFS (21^{o} 21.848' N, 157^{o} 42.584' W) in June 1998. We have installed various sensors on the top of the lidar container, including wind speed, wind direction, temperature relative humidity sensors. The lidar data acquisition system was modified to continuously record these parameters with each lidar scan. This modified system has been operational since August 1998.

In order to derive aerosol scattering coefficients from lidar measurements, we require the lidar calibration factor (determined by the laser pulse power and the receiver efficiency) and the aerosol phase function at 180 degrees scattering angle. In order to determine the aerosol phase function we have employed Mie calculations for an assumed aerosol size distribution (Porter and Clarke, 1997). The lidar calibration was then empirically adjusted so that the aerosol scattering coefficients derived from the lidar agreed with those measured with a nephelometer. In order to experimentally test the assumed aerosol phase function, we have designed and tested a polar nephelometer which measures the aerosol phase function and scattering coefficient (Porter et al., 1998).

Lidars also suffer from a near field effect in which light is not focused on the detector. In order to characterize this effect for our system, we have used a spectralon target to measure the near field response as a function of distance. We found that the near field fall off in our system could be accurately modeled down to about 30 m. Once this is corrected for, we should be able to obtain useable scattering coefficients down to this distance.

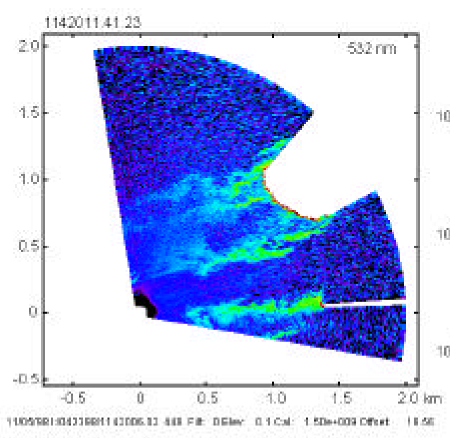

Figure 1: Horizontal lidar scan (532 nm) at the Makai Pier on 4/23/98

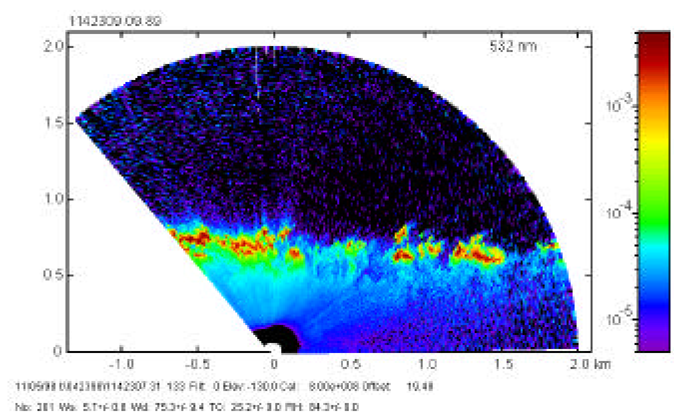

Figure 2: Vertical scan (532 nm) run shortly after the scan in Figure 1

Our measurements at the two sites (Makai pier and Bellows Beach) have shown interesting structure in the aerosol fields. Approximately 1 km offshore from the Makai Research Pier, there are two small islands. These islands can be seen in Figure 1 (left) the white regions where the laser beam is obstructed. Waves break on either side of these islands producing salt spray which is carried towards the shore. It can be seen that as the plumes drift downwind their concentration decreases with distance from the source which is consistent with large salt spray. Figure 2 shows a vertical scan on the same day. The virga falling out of the low level clouds is evident. We often find this virga/drizzle reaches the surface causing large increases in the scattering. Including these effects in optical models will be a challenge as little or nothing is known about their spatial and temporal distribution. We also typically find an enhanced backscatter layer at approximately at 400-600 m which is consistent with the top of the mixed layer.

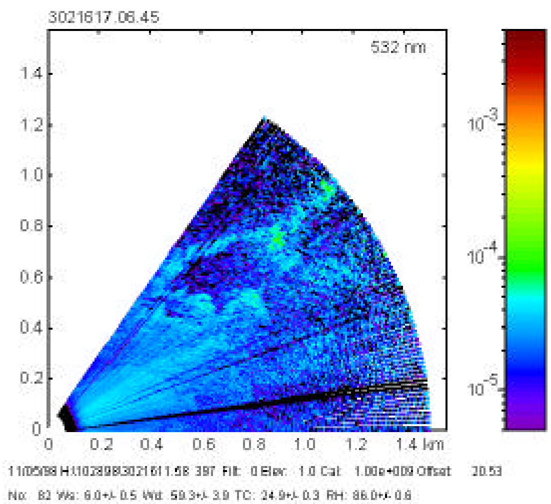

Figure 3: Horizontal scan (532 nm) at Bellows Beach on 10/28/98

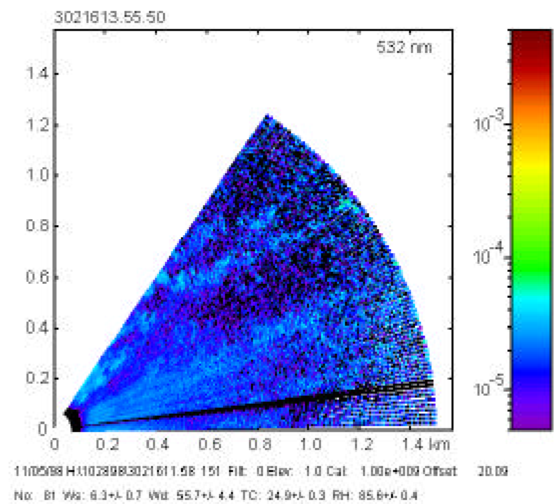

Figure 4: Horizontal scan performed 4 minutes after the scan in Figure 3

The Bellows beach site has an outer reef (~1.3km) where waves first break and a shore break near the lidar (~20m). The outer submerged reef is not continuous but has one major portion (~100 m wide) and several smaller parts. Figures 3 and 4 show two horizontal scans of the scattering coefficient on 10/28/98 which clearly indicate plumes of aerosol coming from these reefs. The scattering coefficients of these plumes are of smaller magnitude than those observed from the islands at Makai Pier and show substantial temporal variation. We also frequently see enhanced near shore (<600 m) scattering of the type appearing in the right hand plot. Although the origin of this near shore scattering is not clear in these plots, later vertical scans suggest that it may be drizzle/virga falling from near shore cloud development which we have seen visually on many occasions (Woodcock, 1953). The black lines are due to RF interference at the Bellows site causing occasional false triggers in the data acquisition system.

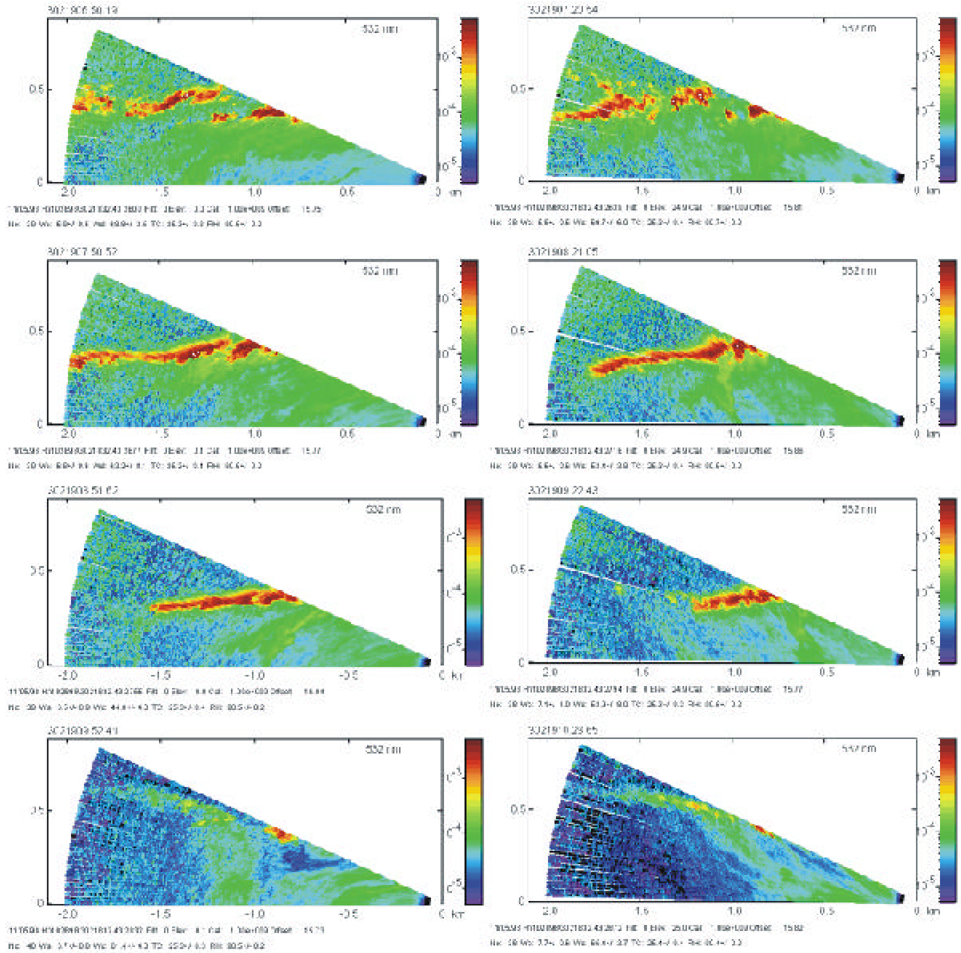

Figure 5: Series of vertical scans (532 nm) shot at 30 sec. intervals at Bellows beach on 10/28/98

Figure 5 shows vertical scans at the Bellows Beach site that were recorded on 10/28/98 at 30 second intervals. Several downdraft events of drizzle/virga are evident, most of them reaching the surface.

Again at this site, it appears that much of the coastal scattering is caused by cloud related processes. This is somewhat surprising as we expected more contribution from ocean-generated spray. As we stated earlier, this implies that models of coastal optical properties must accurately account for micro-scale cloud processes.

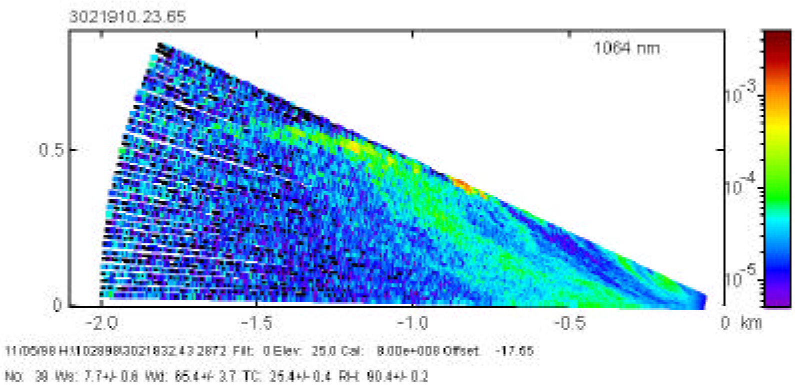

Figure 6: Vertical scan at 1064 nm at Bellows Beach on 10/28/98

Figure 6 shows a vertical scan at 1064 nm recorded simultaneously with the last 532 nm scan in Figure 5. Similar features appear at both wavelengths. Analysis of the differences between the two distributions will proceed when we have absolute calibrations at both wavelengths.The aerosol anomalies apparent in Figure 5 were also detected by instruments located on the adjacent Bellows tower operated by Dr. Clarkes group. Figure 7 shows a sample of one of these records.

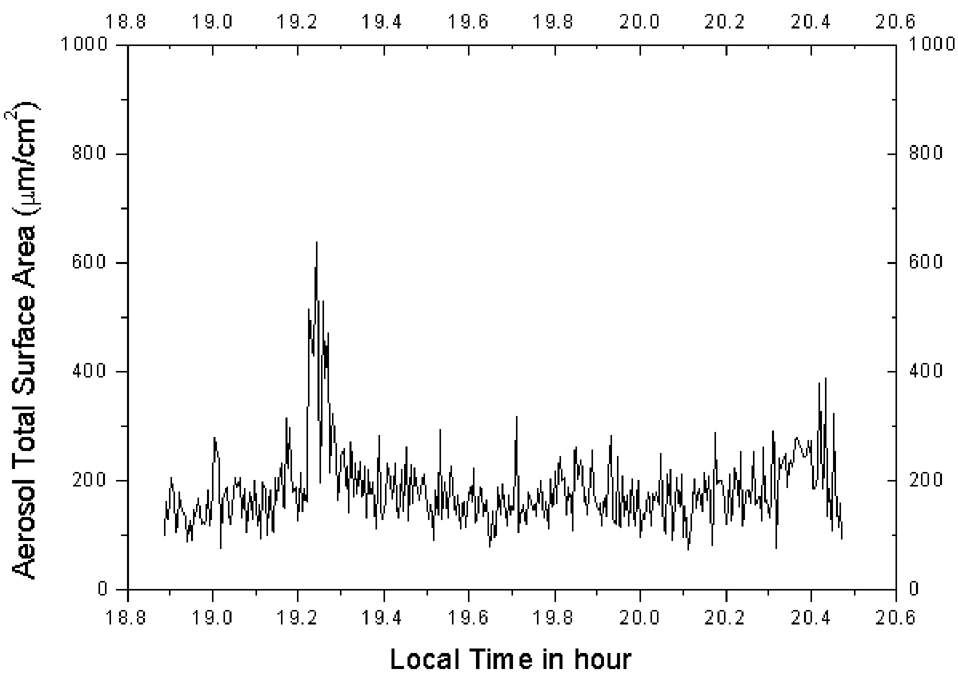

Figure 7: FSSP data recorded shortly after the last lidar scan in Figure 5.

IMPACT/APPLICATION

Our efforts are characterizing the important features needed to adequately model the optical characteristics of the coastal marine environment. The techniques we are using are novel and appropriate for future research. The 3-D patterns of aerosol fields that we have observed indicate that the optical transmission in coastal areas is significantly affected by cloud micro-scale processes which will be challenging to model. The effect of breaking waves was found to be less important at the Bellows site than at the Makai site.

TRANSITIONS

Our lidar measurements are linked to two ONR projects. The proposal "Physicochemical and Optical Characterization of Boundary Layer Aerosol Fields" (PI: Antony Clarke) will provide data which can help to calibrate our lidar measurements. We are collaborating with Dr. Kusiel Shifrin at OSU to derive aerosol size distribution with our multi-wavelength measurements (Shifrin et al. 1998).

RELATED PROJECTS

1) We (PI: Shiv Sharma) are developing a water vapor DIAL lidar system under the project "Center for the study of water vapor fields and their radiative effects over Hawaii". This project is funded by NASA and will be operational along with our existing ONR lidar system. This enhanced capability will improve the utility of the ONR lidar to provide rapid measurements of water vapor in the atmosphere.

2) We (PI: John Porter) are currently funded by NASA, in two separate efforts, to test satellite derived products from the SeaWifs and various EOS-AM satellite sensors. This is part of the SIMBIOS effort and the EOS-AM validation effort. The lidar measurements will occasionally be used for these efforts.

3) We (PI: Barry Lienert) anticipate funding from NOAA/Sea Grant College for developing an airborne lidar system to measure oceanic fluorescence and hydrological properties.

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